Farmers' vulnerability to climate change-induced water poverty in spatially different agro-ecological areas of Northwest Ethiopia

Menberu Teshome

ABSTRACT

This study assessed the vulnerability levels of farmers to water poverty in spatially different agro-ecological areas of Northwest Ethiopia, where severe climate change risks exist. Data were collected from 525 randomly selected rural households in *dega* (highland), *woyna-dega* (midland) and *kola* (lowland) agro-ecological zones using questionnaires. This study also used secondary meteorological data. Rural households' exposure and vulnerability levels were analyzed using simple regression, standardized precipitation index, drought intensity and climate-vulnerability index (CVI). The study also used the United Nations Development Program's (UNDP's) equation to measure vulnerability differential across agro-ecologies. The indicators were normalized as indices by considering functional relationships of indicators with vulnerability. Composite vulnerability indices were calculated using the equal weighting method. The result indicates that households in *kola* agro-ecology were found to be more exposed and vulnerable (0.62 score) to climate change-induced water poverty than those households in *woyna-dega* (0.49) and *dega* (0.30 score). The assessment of vulnerability at the appropriate spatial scale is a key step in designing context-specific adaptation responses that are effective in addressing the needs of the poor people who reside in different agro-ecological settings.

Key words | drought intensity, simple regression, standardized precipitation index, vulnerability index, water poverty

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INTRODUCTION

Scientific evidence indicate that global climate change, caused by increasing concentration of greenhouse gases in the atmosphere, has emerged as one of the most pressing international environmental challenges of the 21st century (IPCC 2007; Houghton 2009). After the Industrial Revolution, human-induced climate change has added new unpredictable threats to societies due to not only the occurrence of extreme weather events but also for failures to adequately address pervasive poverty (Schipper 2004) and severe land degradations (World Bank 2008; Food & Agricultural Organization (FAO) 2009).

Although the valuable components of natural capital such as land, water and vegetation are basic providers of goods and services, and are highly valued by society (Sullivan 2002; Barungi & Maonga 2011), they have been experiencing persistent pressure and stresses from a range of direct and indirect driving forces (Sullivan 2002). Climate change deteriorates water and land resources through increasing evapo-transpiration, severe degradation and soil erosion, and ultimately harms fauna and flora. Indeed, environmental changes are severely affecting households leading them to live in insidious poverty (Barungi & Maonga 2011).

Global warming has imposed adverse effects on the hydrological cycle that affects fresh water resources highly sensitive to variation in weather and climate (IPCC 2001,

doi: 10.2166/wcc.2015.140

2007). The changes in global climate might change the nature of precipitation, evaporation, stream flow, quantity and quality of fresh water, and the frequencies of droughts and flood episodes. Precipitation is unevenly distributed around the globe; some parts of the world may face significant reductions in precipitation or major alterations in the timing of wet and dry seasons, while some others experience abundance (Sullivan 2002; Sullivan & Huntingford 2009).

In its Fourth Assessment Report, the Intergovernmental Panel on Climate Change (IPCC) states that Africa is one of the most vulnerable continents to climate change and climate variability (2007) and that by the 2050s, 350–600 million Africans will be at risk for increased water stress (IPCC 2007; Hahn *et al.* 2009). Over 300 million people in Africa still do not have reasonable access to safe drinking water. An even greater number of people lack adequate sanitation. Over 400 million people are living in at least 17 water scarce African countries. Their lack of adequate water will severely constrain food production, ecosystem protection and socioeconomic development. Hahn *et al.* (2009) notice that the convergence of multiple stressors combined with lack of resources for adaptation are presenting critical challenges for African communities struggling to adapt to climate change.

Many aspects of the environment, economy and society are dependent upon water resources, and changes in the hydrological resource base have the potential to severely impact on environmental quality, economic development and social well-being. There are both supply-side and demand-side pressures on water resources. The supply-side pressures include climate change (reducing or increasing the amount of water available), and environmental degradation, where for example pollution reduces the amount of water available for use. Demand-side pressures include population growth and concentration, leading to increased water demands for domestic, industrial and agricultural purposes.

Ethiopia has historically suffered from climate variability and weather extremes. Rain failures have contributed to crop failures, deaths of livestock, hunger and famines in the past. Today, Ethiopia ranks 11th of 233 countries and other political jurisdictions in terms of its vulnerability to physical climate impacts, and 9th in terms of overall vulnerability, defined as physical impacts adjusted for coping ability (African Climate Change Resilience Alliance, ACCRA 2011). Droughts, floods, severe land degradations, and other extreme weather events coupled with population pressure on the fragile ecosystem aggravate impacts of climate change on poor people's livelihood resources like water (Admassie *et al.* 2006; You & Ringler 2010).

Although climate change is just one of the pressures facing water resources and their management, there have been few assessments (Hassan 2006) regarding the potential impact of climate change on water resources. Site-specific issues also require site-specific knowledge and experience. The purpose of this paper is, therefore, to analyze the vulnerability status of rural households to water poverty in relation to changes in climatic parameters in spatially different agro-ecological setting of northwest Ethiopia.

RESEARCH METHODS AND PROCEDURES

Site selection and study area

Three spatially different *woredas* (districts) were purposely selected from northwest Ethiopia, namely Dabat, Dembia, and Simada (see Figure 1). The three study sites stretch from the Abay-Beshilo (Upper Blue Nile) Basin to the northern (Semien) highlands, bearing similarities in some socio-economic aspects, but differing greatly in agro-ecological setting. Research areas included 11 *kebeles* (lowest administrative tiers of Ethiopia) selected from the three respective agro-ecological zones.

According to a World Vision Dembia Area Development Program document, Dembia *woreda* is almost entirely placed within the *woyna-dega* (midland) agro-ecology with an elevation ranging from 1,700 to 2,600 m above sea level and experiences uni-modal (locally known as *Meher*) rainfall pattern from mid-June to September with average annual rainfall of 870–1,394 mm. The topography of the area is characterized by 87% plain, 5% mountainous, 4.8% valleys and 3.2% swampy (World Vision Office Document 2007). The *woreda* is also entirely located in the Tana '*Zuria*' livelihood zone where most wealth groups enjoy relatively good agricultural production. Crop sales provide three-quarters of income for all wealth groups. Livestock are in good condition promoted by relatively good availability of pasture and water resources. Road infrastructure

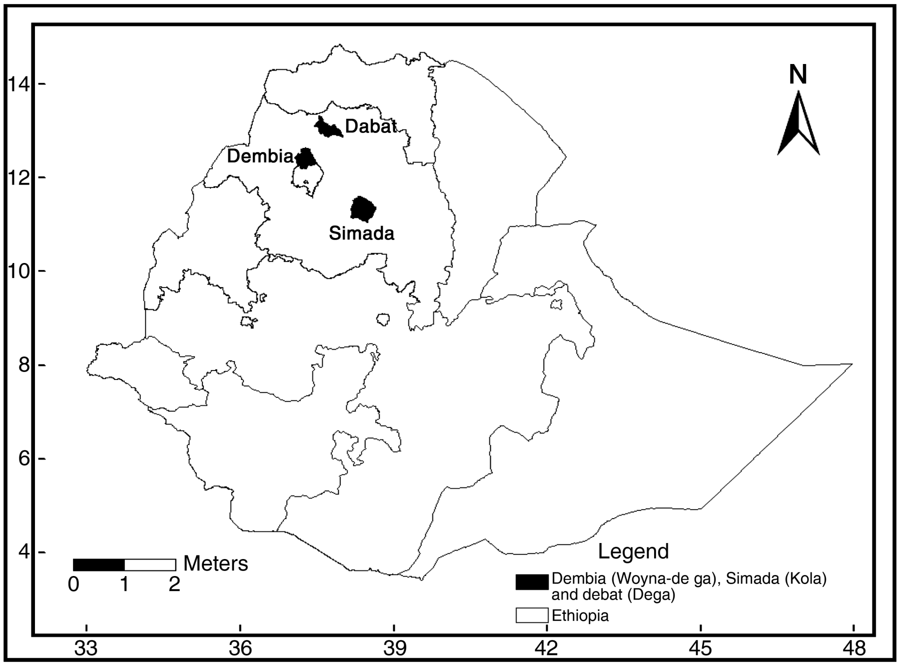


Figure 1 | Study *woredas* in the national and regional setting.

is relatively good and facilitates marketing of agricultural produce.

Dabat is located close to the highest peak of Ethiopia (Ras Dejen) covering a total area of 122,328 hectares and is divided into 26 *kebeles*. It is bounded by Debark *woreda* in the north, Wogera in the south, Tsegede and Tach Armachiho in the west, and Debark and Wogera *woredas* in the east. The altitude ranges from 1,500 to 3,300 m above sea level (asl). Over half of its total area falls in *dega* agro-ecological area (Dabat *Woreda* Communication Office 2013). The selected sites from this *woreda* placed within the north highland wheat-barley-sheep livelihood zone having relatively abundant water resources (ACCRA 2011).

Dabat receives rainfall amounts ranging from 700 to 2,000 mm. Rain in March and April plays a critical role in land preparation for planting in May and June. The major rainfall extends from June to September although less frequent and smaller amounts of rainfall are still expected in October. Early maturing crops are harvested in mid-September, and a second crop is planted in flat areas where the crop is expected to grow on residual soil moisture and the small rains that follow in October. Crop harvest extends from October to December (ACCRA 2011). The main crops are barley, wheat, and beans while the main livestock are sheep, cattle and equines. This *Dega* mixed farming zone faces food deficit every year. The regional government classified it as one of the food insecure *woredas* lacking basic infrastructure facilities. The very poor and poor depend on labor markets for their income and many people are dependent on Productive Safety Net Program (PSNP) to supplement their food requirements (ACCRA 2011).

Study sites of *kola* agro-ecology are located in the Abay-Beshilo (Upper Blue Nile) Basin livelihood zone of Simada *woreda* where famine, drought, land degradations and food insecurity are serious problems particularly over the last two to three decades. The *woreda* is bordered on the southeast by the Beshilo River, which separates it from the South Wollo Administrative Zone, on the southwest by the Abay River, which separates it from East Gojam Zone, on the northwest by Estie *woreda*, and on the north and northeast by Lay Gaynt and Tach Gaynt *woredas*, respectively. Part of its boundary with Estie *woreda* is defined by the Wanka River, a tributary of the Abay. The *woreda* is located 774 km north of Addis Ababa and 209 km southeast of Bahirdar and Mount Guna. It is totally inclusive in the Abay River Basin (Upper Blue Nile Basin of Ethiopia).

The *woreda* is agro-ecologically described as *kola* (60%), *woyna-dega* (30%) and *dega* (10%) (Tibebe 2008). The area has high rainfall for the two months of summer with less or no rainfall during other months of the year. Nevertheless, the wet season extends mostly from mid-June to the beginning of September. Almost all population living in the *woreda* is dependent on mixed farming. The major crops grown in *kola* are sorghum, haricot bean, maize, and *teff*.

Data collection

Assessing the vulnerability levels of rural households to climate change induced water poverty requires high quality data and/or information. This includes data on sources of water for consumption, number of months households were faced with water shortage per year, whether water was regularly available or not, average liters of water stored per household per day, average time households travel to reach sources of water, frequency of conflict over water resources in the locality, and situation of access to water for irrigation. These primary data were collected using a questionnaire survey, focus group discussions, field observation, and interviews.

The household questionnaire survey was conducted in the period between March and September 2012 from 525 sample rural household heads using enumerators with close supervision of the author and supervisors. The Yemane's (1967) statistical formula referred by Israel (1992) was checked within the determination of the sample household size for a better representation of the study population. Then, the 525 households were distributed to each *kebele* using the probability proportional to size (PPS) method to ensure equal representation of households as there are different household sizes in each agro-ecological zone and *kebele*. When difficulties arose in meeting the selected household due to absenteeism or unwillingness, they were replaced by the household listed next to them. Most of the farmers were interviewed on the homesteads and a few of them were consulted on Saturdays, Sundays, and other holidays around churches and community gathering places.

Methods of data analysis

Analysis of water and climate change indicators demand various quantitative methods complemented with qualitative data analysis methods. The quantitative methods include simple regression, standardized precipitation index and climate vulnerability index complemented with descriptive statistics like mean, percentage, maximum and minimum values.

Simple regression

When we examine the relationship between quantitative outcome and single quantitative explanatory variable, simple linear regression is the most commonly used method in order to detect and characterize the long-term trend and variability of temperature and rainfall values at annual time scale. The parametric test considers the simple linear regression of the random variable Y on time X. The regression coefficient *a* (or the Pearson correlation coefficient) is the interpolated regression line slope coefficient computed from the data. The statistic as used by Mongi *et al.* (2010) is

$$\mathrm{Y} = \dot{\beta}\mathrm{x} + \mathrm{c} \tag{1}$$

where Y is the physical factor (changes in rainfall and temperature) during the period, β is the slope of the regression equation, x is the number of years from 1979 to 2010, and c is the regression constant.

Standardized precipitation index (SPI)

The standardized precipitation index (SPI) was used to identify droughts (duration, magnitude and intensity) across the years during 1979 to 2010. The SPI is a statistical measure indicating how unusual an event is, making it possible to determine how often droughts of certain strength are likely to occur. The practical implication of SPI-defined drought, the deviation from the normal amount of precipitation, would vary from one year to another. It can be calculated as

$$\mathrm{SPI} = \frac{X - \overrightarrow{X}}{\sigma} \tag{2}$$

where SPI refers to rainfall anomaly (irregularity) on multiple time scales, X represents annual rainfall in the year t, $\overrightarrow{X}$ is the long-term mean annual rainfall, and σ represents the standard deviation of rainfall over the period of observation (McKee *et al.* 1993; Agnew & Chappel 1999, cited in Woldeamlak 2009). Accordingly, the drought severity classes are: extreme drought (SPI < −1.65); Moderate drought (−0.84 > SPI > −1.28); Severe drought (−1.28 > SPI > −1.65), and No drought (SPI > −0.84).

Having quantified the SPI values, drought duration, magnitude and intensity were analyzed. Drought duration is the period between when a drought starts and ends expressed in months or years. McKee *et al.* (1993) developed a classification system to define drought intensities from the SPI values. In their classification, a drought event occurs any time the SPI is continuously negative and reaches an intensity of −1.0 or less. The drought event ends when the SPI becomes >− 0.84. Each drought event, therefore, has a duration defined by its beginning and ending, and intensity for each month that the event continues. The positive sum of the negative SPI for all the months or years within the period of drought event can be termed as drought magnitude (DM) (McKee *et al.* 1993). Mathematically it can be expressed as

$$DM = \sum_{j=1}^{x} -(SPI\, ij) \tag{3}$$

where j starts with the first month or year of a drought and continues to increase until the end of the drought (x) for any of the i time scales (the i month or year from the observation period).

Drought intensity (DI) is the ratio of the drought magnitude to the duration event, which can be expressed as Mi/Li where Mi is drought magnitude and Li is the drought duration calculated from the SPI. Although most drought analysis used the monthly time scale, the yearly scale was selected for the purpose of this study because of the comparative nature of the study. If the monthly scale had been used, the presentation would have been complicated and would have made the results and discussion bulky.

Climate vulnerability index (CVI)

CVI provides a measurement of values, which represent human vulnerability to water poverty because of climate change. High values of the CVI (which ranges from 0–1) indicate a greater risk of being vulnerable to changing climate conditions (Sullivan & Huntingford 2009). Accordingly, an assessment of vulnerability status of rural households to measure their access to water resources was done using climate vulnerability index (CVI). Indices were constructed using equal weighting method (Hahn *et al.* 2009) and the indicators were normalized as an index using the equation adapted by UNDP to calculate life expectancy index and Sullivan *et al.* (2002) to analyze water poverty index (see Equations (4)–(6)).

The indicators listed in Table 1 above were converted into standardized index by Equation (4):

$$\text{Climate Vulnerability Index} = \frac{\text{Observed values} - \text{Minimum values}}{\text{Maximum values} - \text{Minimum values}} \tag{4}$$

For example, when the average time taken to reach water source ranges from 1 to 140 minutes in the households surveyed, these minimum and maximum values were used to transform this indicator into a standardized index value to be integrated into the physical assets of the CVI. For variables that measure frequencies, such as percent of households that had heard about conflicts over water resources in their community, the minimum value is set at 0 and the maximum at 100.

In the case of adaptive capacity indicators, the author used the inverse scoring technique in order to standardize the values for each indicator by Equation (5) as was used by an interdisciplinary team formed to prepare national adaptation program of action (NAPA) for Ethiopia in 2007 to analyze cost factors of adaptation to climate change (International Crop Research in Semi-arid Tropics (ICRISAT) 2006; NMSA 2007).

$$\text{Inversed Climate Vulnerability Index} = \frac{\text{Maximun values} - \text{Observed values}}{\text{Maximum values} - \text{Minimum values}} \tag{5}$$

According to these techniques, an indicator with the least value will have the highest standardized value. Accordingly, the standardization process was completed for all indicators under each component. For example, some indicators such as the average liters of water stored per household daily decrease vulnerability. In other words, it could be assumed that a household who stored much water per day is less vulnerable than a household who stored little. By taking the inverse of the crude indicator, one can create a number

Table 1 | Indicators for water and hypothesized relationships to vulnerability for the three agro-ecologies

Explanations of specific indicators	Hypothesized relationships to vulnerability
Standard deviation of daily average maximum temperature by month	Exposure ↑ as maximum Tσ ↑ vulnerability ↑
Standard deviation of daily average minimum temperature by month	Exposure ↑ as minimum Tσ ↑ vulnerability ↑
Average monthly standard deviation of rainfall (1979–2010/11)	Exposure ↑ as rainfall deviation ↑ vulnerability ↑
Average number of hazards occurred in the past 10 years	Exposure ↑ as frequency of droughts ↑ vulnerability ↑
HHs[1] reported family member faced injury/death by climate hazards	Health Sensitivity ↑ as injury and death ↑ vulnerability ↑
HHs who use water from unprotected sources (river, pond, spring)	Sensitivity ↑ as utilizing unprotected water ↑ vulnerability ↑
HHs who don't have access to regular water supply	Sensitivity ↑ as pop. with no regular water ↑ vulnerability ↑
Average number of months with water shortage	Sensitivity ↑ as No. of food shortage months↑ vulnerability ↑
Average liters of water used by households per day	Sensitivity ↑ as water consumption ↓ vulnerability vulnerability ↑
Time HHs take to reach water sites in minutes	Sensitivity ↑ as distance to water sources ↑ vulnerability ↑
HHs reported water conflicts in their communities	Exposure ↑ as people reported conflict ↑ vulnerability ↑
HHs who have no access to irrigation water (IW)	Coping-adaptive capacity ↑ as accessed IW ↑ vulnerability ↓

Notes:
[1]Households.
Tσ = standard deviation of temperature.

that assigns higher values to households with a little water and vice-versa. The maximum and minimum values were transformed following this logic and used Equation (5) depicted above to standardize these indicators.

Every score for each indicator is expressed in the same standardized unit (on a 0 to 1 scale); 0 denotes least vulnerable or no vulnerability and 1 denotes most vulnerable. This allows calculation of the average scores which can be done in two ways: by attaching equal importance (simple average of the standardized scores of each criterion for a given indicator) or by attaching different weights to each indicator. In this study, simple averages of standardized scores were calculated for the sub-components using Equation (6):

$$\text{Average Climate Vulnerability Index} = \frac{\sum_{i=1}^{n} \text{Index}}{n} \tag{6}$$

where Average Index is one of the components of temperature change (Tc), rainfall variability (Rv), hazard frequency (Hf); the index represents the sub-components, indexed by i, that make up each component, and n is the number of indicators in each component. Climate vulnerability index equals the weighted average of the three major components. This analysis was done by using SPSS-16 and MS-excel work sheet.

RESULTS AND DISCUSSION

Temperature trends and anomalies

Temperature is a very important climatic variable in the study of vulnerability of agrarian communities to climate change impact. Evidence indicate that the mean temperatures have changed through time in Ethiopia (National Meteorological Services Agency (NMSA) 2001, 2007). The same temperature trend was detected in *dega*, *woyna-dega*, and *kola* agro-ecological areas of northwest Ethiopia over the past 32 years (see Figure 2).

Figure 2 presents the average temperature trends of the three study sites over 1979 to 2010 period. The estimated trend line for average annual temperature in *dega* is $y = 0.040x + 18.32$ and $y = 0.052x + 18.49$ in *woyna-dega* while it is $y = 0.042x + 19.40$ for *kola*. The trend line has a positive slope indicating that the average temperature has increased by 1.2 °C in *dega*, 1.3 °C in *woyna-dega*, and 1.61 °C in *kola* sites over the period considered (32 years). On decadal time scales, it rose by 0.4 °C in *dega*, 0.4 °C in *woyna-dega*, and 0.5 °C in *kola*. This indicates that there was a faster rate of temperature increase in *kola* and *woyna-dega* than in *dega* agro-ecological areas. The rate of increase in the three sites was also faster

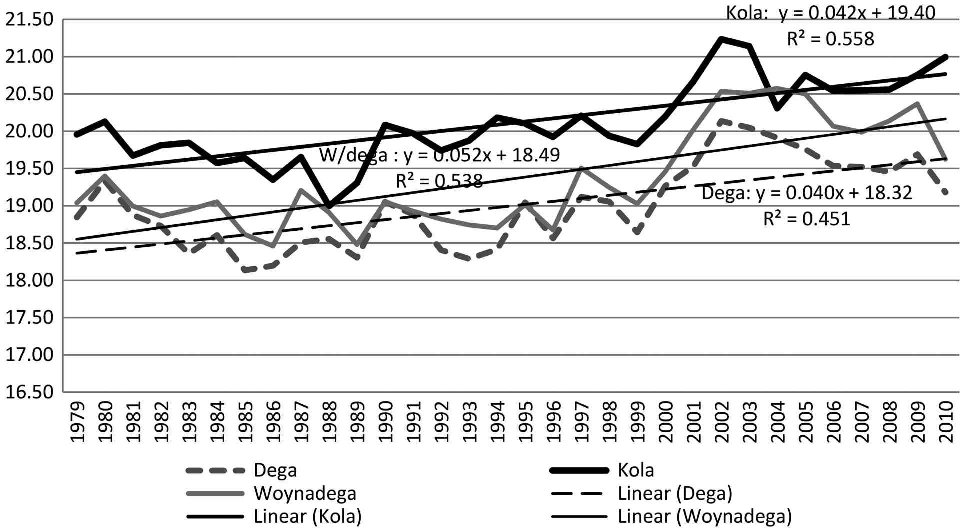


Figure 2 | Average temperature trends by agro-ecology, W/dega = Woyna-dega. (Source: computed from Global Weather Data, http://globalweather.tamu.edu/).

than the national level temperature rise (0.2–3 °C per decade), which was observed over the past 55 years. This result is also supported by 95% of the surveyed households. While the highest temperature increment was detected from the meteorological data in *woyna-dega* agro-ecology, the highest perception of temperature rise was reported by the households in the same agro-ecological setting.

Three distinct periods can be noted from Figure 2: the first is from 1979 to about 1989 where air temperature is actually decreasing over that period. Then the next is the period from 1989 to about 2002 or 2003 where the air temperature is increasing slightly and the third period is from 2003 to 2010 where again, air temperature was actually decreasing over that period. Each of these sub-periods would dramatically affect drought vulnerability.

Maximum temperature increased faster while the minimum temperature increased gradually in the *dega* site. For example, while the maximum temperature rose by 1.7 °C, the minimum rose by 0.8 °C over the past 32 years. In terms of decadal time scale, the increase in maximum temperature was 0.5 °C while the minimum was 0.2 °C per decade. According to the survey result, nearly 87% of the respondents supported these increasing trends of temperature. Although the rate of minimum temperature increase is almost similar to the national level increase (0.3 °C per decade), the maximum increasing rate is quite different from that of the rate of increase observed in Ethiopia (0.1 °C per decade). Only 9.3% of the surveyed households in *dega* noticed the contrary, a decrease in temperature, whilst 3.9% of them have not noticed any change in temperature.

Both maximum and minimum temperatures over the past 32 years (1979–2010) increased in the *woyna-dega* zone. Similar to *dega* site, maximum temperature increased faster than the minimum temperature. For example, the maximum temperature increased by 1.6 °C while the minimum temperature increased by 1.0 °C. In decadal time scale, the maximum temperature rose by 0.5 °C and the minimum by 0.3 °C per decade. This trend was again supported by 95% of the surveyed households who observed increasing temperature trend over the past 20 years. Only 2% of the households noticed a decrease in temperature, and only 1.5% of them have not noticed any temperature change.

An increasing trend of minimum and maximum temperatures was also detected in the *kola* study site from 1979–2010. The simple regression result indicates that the maximum temperature increased by 2.17 °C and the minimum rose by 1.0 °C in the same period (0.7 °C and 0.3 °C per decade, respectively). In *kola* site, the rate of temperature change was found to be faster than in *dega*, *woyna-dega*, and national level rate of increase (National Meteorological Services Agency (NMSA), 2001, 2007) while maximum temperature in *woyna-dega* site was somewhat lower than those of in *dega* and *kola* sites. Only 4.2% of the households in *kola* noticed a decrease in temperature, while only 6.1% of them have not noticed any change in temperature.

The direction of the temperature trend in the three study sites is consistent with the findings of Mongi *et al.* (2010) for Tanzania, which found that both minimum and maximum temperatures showed increasing trends. However, in Tabora Urban and Uyui Districts of Tanzania minimum temperature increased faster while maximum temperature increased gradually. These increasing temperature trends in the three sites has paramount impact on water, land and vegetation resources through worsening evapo-transpiration with negative consequences on the productive capacities of these valuable resources.

In addition to an increasing temperature trend, greater temporal variability was observed in the three agro-ecological areas over the same period (1979–2010). The deviation was calculated using the SPI formula based on Mongi *et al.* (2010).

Figure 3 demonstrates the maximum and minimum temperature deviation from the long-term average temperature in *dega* from the period 1979 to 2010 average temperature. It is clear from the figure that around 1981 there was not much deviation both in maximum and minimum temperatures from the long-term average temperature. Since then both maximum and minimum temperature deviations went down until 1989 and continued until 1994 with fluctuation. In 1981 and 1982, equal variations (from the long-term average maximum and minimum temperatures) were detected in maximum and minimum temperature with a certain decline as compared with the previous years. Since 2000, both the maximum and the minimum temperatures increased with greater fluctuations over time. While the minimum temperature continued its increment, the maximum temperature decreased after 2003 though after 2001 both the maximum and minimum temperature deviations were above the long-term average temperature except for a certain decline in maximum temperature in 2010.

Figure 4 demonstrates the maximum and minimum temperature deviations from the long-term average temperatures for *woyna-dega* study site. It is clear from the figure that until 1984 the deviation between maximum and minimum temperatures was almost similar. After 1984, increasing trend of deviations were detected both in the minimum and maximum temperatures with greater fluctuations over time. Analysis of temperature trend showed similar trends as the one reported by IPCC (2007) and Mongi *et al.* (2010) both of which pointed out that increasing temperature trend in the tropical and subtropical regions of the world is very high (IPCC 2007).

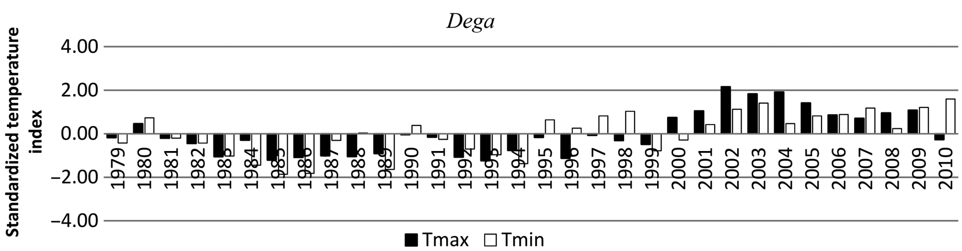


Figure 3 | Long-term maximum (Tmax) and minimum temperature (Tmin) deviations in *dega* agro-ecology. (Source: computed from Global Weather Data, http://globalweather.tamu.edu/).

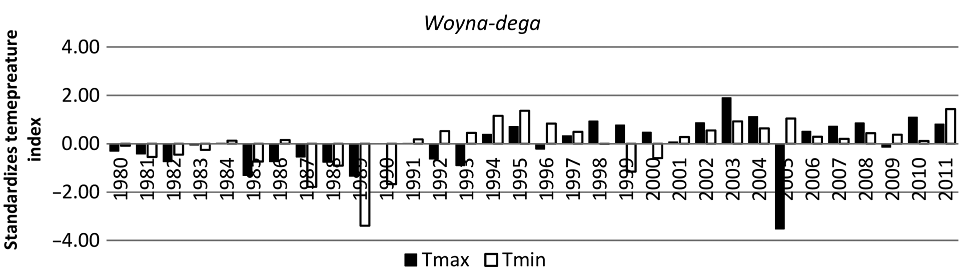


Figure 4 | Long-term maximum and minimum temperature deviations in *woyna dega* (2 years moving average). (Source: computed from Global Weather Data, http://globalweather.tamu.edu/).

Bring Fig 5 here

Figure 5 demonstrates the maximum and minimum temperature deviations in the *kola* site. It is clear from the figure that, similar to the *woyna-dega* study site, both maximum and minimum temperature deviations have shown increasing trend as compared with the long-term average temperature. Although there are still fluctuations, the rate of increase in both maximum and minimum temperatures is much faster in *kola* site than in *woyna-dega* site. With regard to long-term temperature deviation/anomaly, the results in this study are in line with the findings of several other empirical works (Mongi *et al.* 2010; IPCC 2013). The recent IPCC (2013) report stated that in addition to multi-decadal warming, global mean surface temperature exhibits substantial decadal and inter-annual variability. Due to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends.

Long-term inter-annual rainfall and variability and change

For computing the long-term inter-annual rainfall variability and change, simple regression (Equation (1)), was used as was used by Mongi *et al.* (2010) and Gbetibouo (2009). The result indicated that there is significant inter-annual variability of rainfall and rate of decline across all the three study sites. Figure 6 illustrates the long-term distribution and rates of change in rainfall in three study sites from the years 1979 to 2010. It is clear from the Figure that the total annual rainfall distribution is declining from time to time. However, long-term rainfall change from 1979 to 2010 appeared to decrease at statistically non-significant rates ($R^2 = 0.066$ for *dega* and for *woyna-dega* and 0.040 for *kola*). The main problem is the timing (late onset and early cessation) and failing in intense episodes in very short duration.

The long-term reduced amount of rainfall calculated using simple regression for the observation period indicated that the rainfall declined by 46.78 mm in *kola*, 516.99 mm in *woyna-dega*, and 277.82 mm in *dega* over the past 32 years (14.62, 49.057, and 71.19 mm per decade, respectively) (see Figure 6). These results are in line with several empirical research findings. For example, the AACCRA (2011) assessment report which indicated that the rainfall has shown a decreasing trend around Debark *woreda* (near *dega* site).

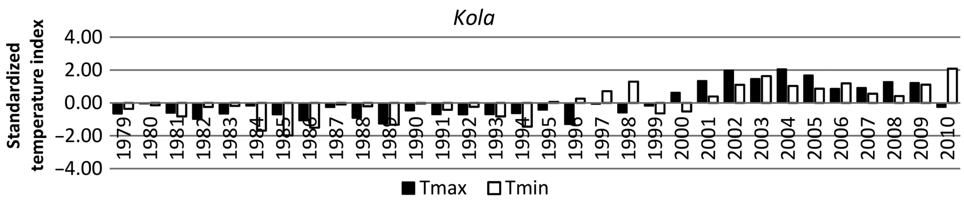


Figure 5 | Long-term maximum and minimum temperature deviations for *kola* agro-ecology. (Source: computed from Global Weather Data, http://globalweather.tamu.edu/).

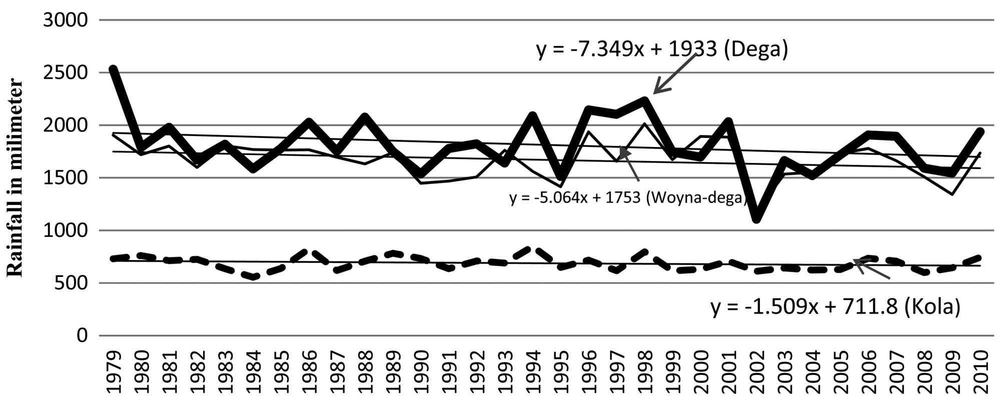


Figure 6 | Long-term trends of rainfall by agro-ecology (1979–2010). (Source: computed from Global Weather Data, http://globalweather.tamu.edu/).

The study made in Tanzania by Mongi *et al.* (2010) also supported this finding, which declared decreasing trends of rainfall for the last 35 seasons from 1973/74 to 2007/08. Similarly, in other regions of Africa, Gbetibouo (2009) in South Africa and Mertez *et al.* (2008) in the Sahel region of Africa, also found decreasing rainfall trends over the past decades. In the present study, however, the decreased amount of rainfall in the observation period is smaller in *kola* than in *dega* and *woyna-dega* study sites. The reason is that rainfall was already very low in *kola* before the period considered.

Long-term drought analysis using SPI (1979–2010)

Drought is a natural hazard, which can be marked by precipitation deficiency that threatens the livelihood resources and overall development efforts of nations or specific places through exacerbating water shortage for some activity or for some group. Therefore, analysis of drought frequency/pattern, duration, magnitude and severity is in high demand for designing appropriate actions. The standardized precipitation index (SPI) results illustrated in Figures 7–9 show the long-term drought patterns for the three agro-ecological sites.

Figure 7 shows the standardized precipitation index for *dega* study site. It is clear from the figure that the rainfall shows alternation of wet and dry years in a periodic pattern. From 32 years of observation, 18 years (56.25%) received below the long-term average rainfall whilst 12 years obtained above average. Consecutive negative SPI values were observed from 2002–2005 followed by a recovery in 2006 and 2007; a fall again in 2008 and 2009 and another rise in 2010 was recorded. The 2002 rainfall amount emerged as the lowest record in the observation period, marking the extreme drought year in the study site. There were five moderate drought years from the 1980 to 2010 such as 1984, 1990, 1995, 2004 and 2009. The high SPI values indicate surplus rainfall and may be associated with

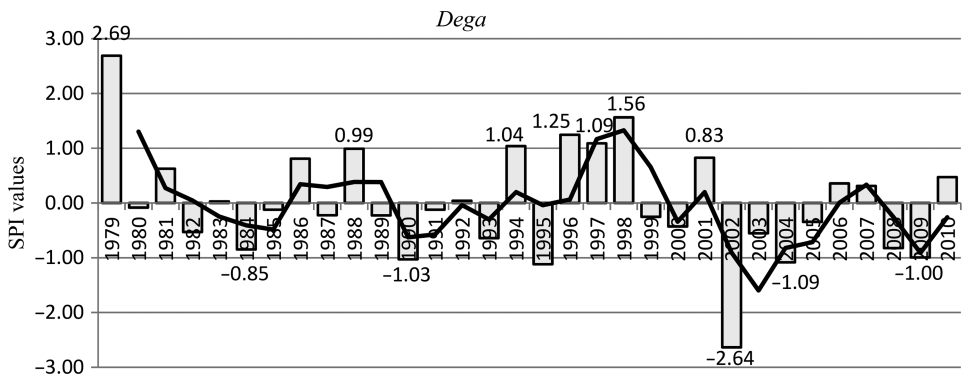


Figure 7 | Standardized precipitation index for *dega* zone with 2 years moving average. (Source: computed from Global Weather Data, http://globalweather.tamu.edu/).

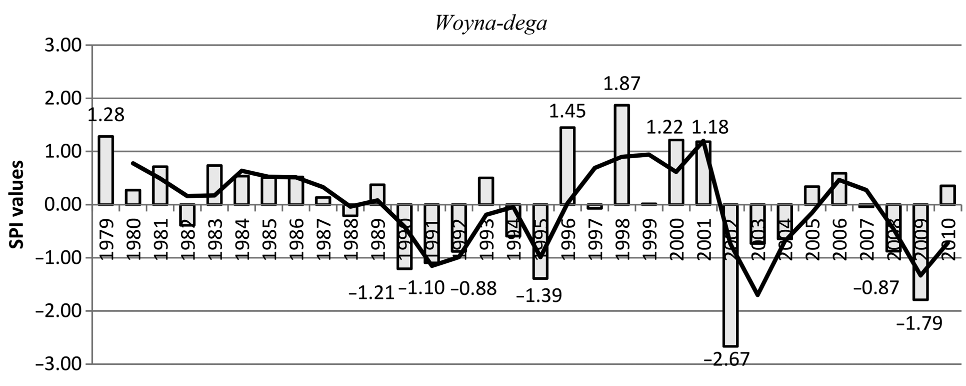


Figure 8 | Standardized precipitation index for *woyna-dega* zone with 2 years moving average. (Source: computed from Global Weather Data, http://globalweather.tamu.edu/).

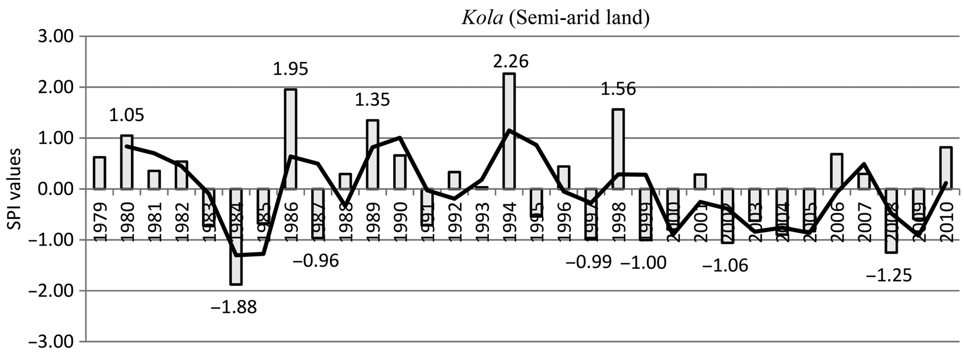


Figure 9 | Standardized precipitation index for *kola* zone with 2 years moving average. (Source: computed from Global Weather Data, http://globalweather.tamu.edu/).

flood years though there is no standard to classify the years in relation to flood occurrence. We can infer that the year 1979 stands first by the probability of flood occurrence with a positive SPI value of 2.69. The years 1998, 1997 and 1996 have positive values with SPI value of 1.56, 1.09 and 1.25, respectively.

The standardized precipitation index (rainfall anomaly – variability and irregularity) for the *woyna-dega* site is shown in Figure 8. Similar to the *dega* site, the rainfall is described by alteration of wet and dry years in a periodic pattern. Out of 32 years, 14 years (43.75%) recorded below the long-term average annual rainfall amount while 17 (53.13%) years recorded above-average. Only the year 1999 received a rainfall amount equal to the long-term average rainfall. Most of the positive SPI values occurred before 1990 (9 out of 12 years). Consecutive negative SPI values occurred from 1990 to 1995 and from 2002 to 2004. The 2002 rainfall amount was the lowest record in the observation period with an SPI value of 2.67. According to the drought assessment method by Agnew and Chappel (1999) cited by Woldeamlak (2009), there were seven drought years in the period spanning from 1979 to 2010 in the site, with varying severity. There were one extreme (2002), and four moderate (1990, 1991, 1992 and 2008) drought years, and one severe drought, which together account for 21.88% of the total number of observations. In contrast, 1998 was the wettest year in the period followed by the year 1996 (almost consistent with the anomalies of Amhara region by Woldeamlak). This wettest year may be associated with the probability of flood incidences with SPI values of 1.87 and 1.45 in the years 1998 and 1996, respectively.

Figure 9 demonstrates the standardized precipitation index for *kola* study site (1979–2010). It is clear from the figure that rainfall is characterized by periodic fluctuation of wet and dry years. Out of 32 years of observation, 15 years (46.88%) recorded below the long-term average annual rainfall and the rest 15 years recorded above the long-term average. Only one year received nearly normal rainfall in the period (1983). Before 1983, the rainfall was above the long-term average whilst from 1983 to 1995, it was below the long-term annual rainfall. Again, in 1986 a positive SPI value was detected in spite of its failure in 1987. Likewise, a positive trend was identified from 1988 to 1990, but drier conditions were experienced in 1991. Once more, slight recovery was observed from 1992 to 1993 with alternate rise and fall until 1998. Most of the negative anomalies occurred after 1998. The amount of rainfall in the years 1984, 1987, 1997, 1999, 2002 and 2008 were the lowest on record in the observation period, marking the worst drought years. Then, the rainfall indicated a recovery in 2006 from the low values of 1999 to 2005, but went down in the next three years (a large decline in 2008 and 2009). Again, the rainfall showed significant recovery in 2010. In the *kola* site, five flood years were identified with high SPI values such as 1980, 1986, 1989, 1994 and 1998 with SPI vales of 1.05, 1.95, 1.35, 2.26 and 1.56, respectively.

Table 2 shows drought duration, magnitude, and intensity in the three study sites based on the calculated SPI values. It is apparent from the figure that long drought duration occurred in the *dega* site with 18 years, 12.16 magnitude, and 0.68 intensities. The drought characteristics in the *woyna-dega* site was found to be 12.54 magnitude and 1.05 intensity in the 12 years of duration whilst in the *kola*

Table 2 | Summary of drought duration, magnitude and intensity by agro-ecology

Agro-ecology	Duration in year	Magnitude (–)	Intensity (–)	Span of time
Dega	18	12.16	0.68	1979–2010
Woyna-dega	12	12.54	1.05	1979–2010
Kola	15	15.53	1.04	1979–2010

(Source: computed from Global Weather Data, http://globalweather.tamu.edu/).

site, 13.53 magnitude and 1.04 intensity were computed in 15 years of duration. This result indicates higher drought intensity was detected for the *woyna-dega* site, and hence it revealed that long drought duration is not necessarily severe. This finding is supported by Otgonjargal (2012) who underlined that a drought year that lasted for 17 months had a higher magnitude (20.1) than a 22 month drought which had a magnitude of 17.3, indicating that longer drought durations are not necessarily the most severe.

Normalization of indicators using functional relationships with vulnerability

The field of climate vulnerability assessment has emerged to address the need to quantify how communities can adapt to changing environmental conditions using different methods by integrating human and physical indicators. These are often combined into a composite index allowing diverse variables to be integrated. Many of these rely heavily on the IPCC working definition of vulnerability as a function of exposure, sensitivity and adaptive capacity (IPCC 2001).

According to the formative measurement model, all variables have an impact on vulnerability. In the empirical considerations, the indicators do not necessarily share the same theme and hence have no intercorrelation (Coltman *et al.* 2008). In order to obtain figures which are free from the units and to standardize their values, variables were normalized so that they all lie between 0 and 1. Value 1 corresponds to the agro-ecology having maximum value and 0 corresponds to the agro-ecology with minimum value of each indicator (Iyengar & Sudarshan 1982; Sullivan *et al.* 2002; ICRISAT 2006; Hahn *et al.* 2009; United Nations Development Program (UNDP) 2010).

This method of normalization takes the functional relationship between the variables and vulnerability (see Table 1). For example, suppose we have collected information on change in maximum temperature or change in annual rainfall or diurnal variation in temperature, it is clear that the higher the values of these indicators, the vulnerability of a place increases as variation in climate change variables increases. In this case, the variables have a positive functional relationship with vulnerability and the normalization is done using the formula indicated in Equation (4). If the indicators are assumed to have inverse relationship with vulnerability, Equation (4) will be inverted to Equation (5) so as to calculate inversed values of the indicators.

Let us now consider the distance household heads take to reach water sites by agro-ecology. Distance to sources of water is maximum in *kola* with a value of 270 minutes and has a minimum value of 3 in *dega*. The observed (average) value for *kola* was found to be 39.54. Hence, the normalization is achieved by using Equation (4). For example, the normalized score for *kola* agro-ecology is

$$\text{normalized value} = \frac{39.54 - 3}{270 - 3} = 0.14$$

In this way the normalized scores for similar indicators for each agro-ecology was computed.

On the other hand, let us consider average liters of water households stored per day. A high value of this variable implies better off households in the agro-ecology and so they will have more capacity to cope with climate change impacts. Therefore, vulnerability will be lower and the amount of water has an inverse functional relationship with vulnerability. In this case, the normalized score was computed using Equation (5).

An average liter of water stored in a household per day found higher in *dega* with a value of 200 liters and it has lower value of 20 in all agro-ecologies. The observed value was 58.29 liters in *dega*, 55.50 liters in *woyna-dega* and 65.06 liters in *kola*. For example, the standardized score for *kola* agro-ecology is:

$$\text{Normalized value} = \frac{200 - 65.06}{200 - 20} = 0.80.$$

In this way, the author computed the normalized scores for each exposure and vulnerability indicator. This method of normalization that takes into account the functional relationship between the variable and vulnerability is important in the construction of indices. If the functional relationship is ignored and the variables are normalized simply by applying Equation (4) the resulting index will be misleading. Thus, while constructing the vulnerability index coefficient, the author was careful to take into account the direction of the functional relationship of each variable to vulnerability. Table 3 presents the summary of climate vulnerability indices (CVIs) results for all indicators of each agro-ecological setting.

Exposure of households to climatic factors

Vulnerability to climate change needs to be analyzed first from the natural science perspective where models provide insights in the potential exposure of a system and resulting adverse effects. From this perspective, IPCC defines vulnerability as a function of the character, probability of occurrence, magnitude and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity (IPCC 2001). In addition, this perspective looks at the magnitude of impacts determined by weather and other climate related events (Brooks 2003).

Table 3 | Normalized values of water resource indicators by agro-ecology

Vulnerability Indicators	Unit	*Dega*	*Woyna-dega*	*Kola*
HHs utilize water from unprotected sources	Percent	0.07	0.08	0.92
HHs have no access to regular water supply	Percent	0.04	0.58	0.75
Average number of months with water shortage	Month	0.01	0.18	0.28
Average liters of water stored per household	Liter	0.82	0.84	0.80
Average time to reach drinking water sources	Minute	0.05	0.06	0.14
HHs reporting water conflicts in their locality	Percent	0.17	0.78	0.51
HHs who have no access to water for irrigation	Percent	0.76	0.74	0.94
Total water vulnerability	**Index**	**0.30**	**0.49**	**0.76**

Source: Household survey, March to September 2012.

The exposure of a system is determined by the amount of stress that impacts the unit of analysis. Exposure can be represented by a change in magnitude, frequency and duration of an extreme climatic event (such as droughts, floods, storms, etc.), climate variability or long-term climate patterns such as increasing temperature and decreasing precipitation to which farmers' livelihood assets like water are exposed (IPCC 2007). Accordingly, exposure indices were constructed using changes in temperature, rainfall and frequency of extreme events for the study locations.

Bring Fig.10 here

Figure 10 demonstrates the households' level of exposure to climate variability and other related hazards (extreme climatic events) in the three agro-ecologies. It is clear from the diagram that there are three main indicators: temperature, rainfall and hazard frequency (climate-related extreme events). In terms of aggregate climate exposure indices, *woyna-dega* and *kola* are found to be more exposed at 0.54 and 0.51 scores, respectively, while only a relatively low exposure status was detected in *dega* at 0.31 exposure index value.

When the exposure indices are compared indicator-wise among agro-ecologies, temperature variability is higher in *woyna-dega* with an index value of 0.66 followed by *kola* (0.54) while the exposure index is relatively low in *dega* (0.37). The exposure index which shows the extent of rainfall variability is slightly higher in *kola* agro-ecology (0.56) closely followed by *woyna-dega* (0.54) while *dega* agro-ecology had a rainfall variability exposure score of 0.43. Again, climatic extreme events were found to be more frequent in *kola* agro-ecology (0.42) followed by *woyna-dega* (0.37). In sharp contrast, a very low exposure index for climatic extreme events (0.08) was constructed in *dega* agro-ecology.

Vulnerability of households to water poverty

Water is the basic natural resource for all forms of life on earth, without adequate supply of it there is no sustainable development and proper environmental functions. Although it is a renewable resource, water is variable in space and time, and is sensitive to climate change and hence it is one of the most critically stressed resources. The quantity and quality of water have played a key role in determining people's residence, economic activities, and quality of life (Sullivan 2002; IPCC 2007; Sullivan & Huntingford 2009).

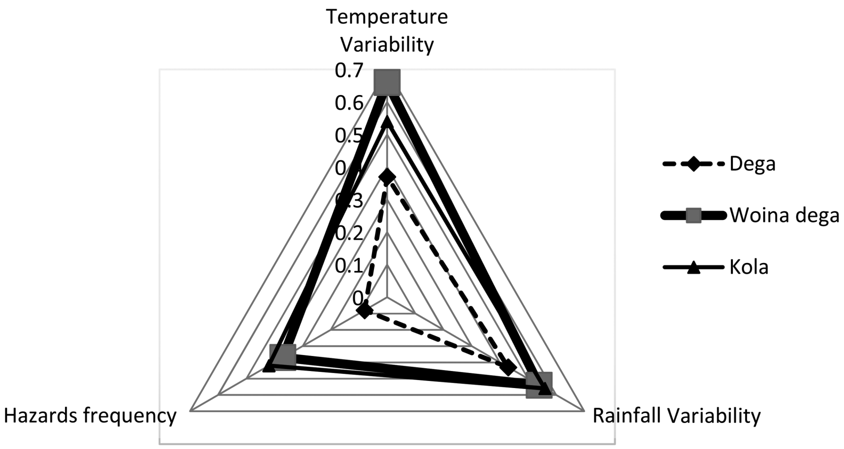


Figure 10 | Vulnerability radar for climatic parameters.

Correspondingly, responses from the survey indicated that 92% of households in *kola* have no access to piped water for domestic use against only 7% in *dega* and 7.5% in *woyna-dega* agro-ecologies. Hence, they are forced to utilize water from unprotected sources (wells, streams, rivers, ponds), indicating water-born health problems.

Rural households travel long distances to fetch water for household consumption. For instance, the survey results in *dega* indicated that 57.4% of the households spent 4–15 minutes to obtain their water supplies, 32% spent from 16 minutes up to half an hour and 10.2% of them required from 35 up to 53 minutes. Only one household took two hours to reach water sources. In the *woyna-dega* site, nearly half of the households (49%) travel from 3 to 15 minutes; 42.2% from 16 minutes to half an hour and 7% from 31 up to 53 minutes. The rest, 2.3% of the households traveled between 70 and 75 minutes to obtain sufficient water. In sharp contrast, less than 20% of the households in *kola* reported traveling from 3 to 15 minutes to fetch water for domestic purposes, while 40.1% were required to travel from about 16 minutes to half an hour. Around 26% of them were traveling between 35 minutes and an hour while 12.3% of them between one and two hours, and the remaining 2% were traveling longer than 2 hours to obtain water. Insert Table 3 here

As can be seen from Table 3, the vulnerability levels of households to climate change-induced water shortage were found to be 0.76 in *kola*, 0.49 in *woyna-dega* and 0.30 in *dega*. It is very clear from the indices that *kola* agro-ecological area is more vulnerable to water stress than *dega* and *woyna-dega* agro-ecological areas as the biophysical and socio-economic contexts were found to be the worst there. Communities are observing negative impacts of drought and extreme events on natural resources such as farmlands, pasturelands, water sources, and vegetation. NGOs and government officials also mentioned the declining availability, productivity and quality of farm and pasturelands.

Over 74% of the respondents from *kola* exceptionally acknowledged the problem of water shortage particularly in drought years, distantly followed by 44% in *woyna-dega*. In sharp contrast, in *dega,* water shortage was only reported by 3.9% of the surveyed households even during drought seasons (see Figure 11). This result reveals the implication of climate change on the hydrology of water systems in

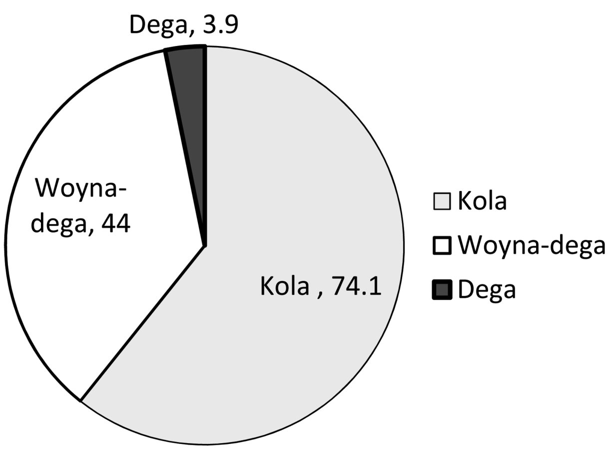


Figure 11 | Percent of households reporting water shortage by agro-ecology.

kola environment, affecting the magnitude and seasonal flow of surface waters, and increasing the frequency of extreme events such as droughts and flood episodes.

According to Hassan (2006), although the predictions vary widely from model to model, all models agree that climate change can reduce river flow by amounts ranging from 15 to 80% of the monthly mean in some months of the year all over the Abay basin. He added that declining trend in river flow causes a complete dry up of small streams, and significant decrease in magnitude of flow of the medium to larger rivers.

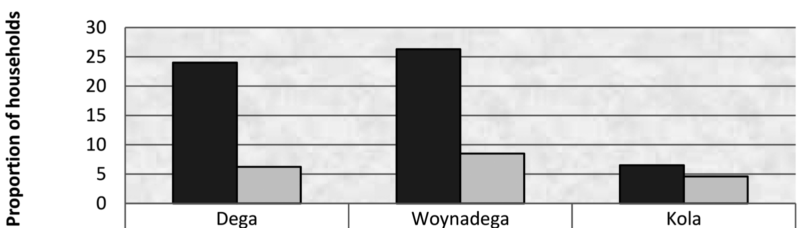
Irrigation is often identified as an effective adaptive strategy to cope with drought in agricultural communities (Luk 2011). The water resource deficit was reflected in terms of irrigation applicants and area coverage indicates access to water for irrigation and buffer the community during times of drought.

Figure 12 demonstrates the percentage of respondents and the cultivated cropland they have used for irrigation purposes. The figure shows that 8.5 hectare of land is used by 26.3% of households in *woyna-dega* followed by 6.24 hectares of land by 24% of households in *dega*. In *kola* agro-ecology only 4.6 hectares of land was irrigated by 6.5% of surveyed households. The surveyed households have very limited access to irrigation with a vulnerability score of 0.94 in *kola*, 0.76 in *dega*, and 0.74 in *woyna-dega*. In the light of this, the FGD discussants and in-depth interviewees in *kola* site strongly complained about the problem of water shortage for different purposes. The increasing run-off, which has affected underground water potential through reducing infiltration of rainwater and intense evaporation from surface water bodies, is a major cause of water scarcity in the study sites.

CONCLUSIONS

This study assessed the vulnerability status of rural households to water poverty in spatially different agro-ecologies of northwest Ethiopia where severe climate change risks exist. The study identified the different vulnerability status of rural households across the three agro-ecological zones. For instance, corresponding to fragile environmental conditions experienced in the *kola* site, exceptionally 92% of the surveyed households have no access to piped water for domestic purposes as compared with *dega* and *woyna-dega* households (<= 7.5%). The majority of the surveyed households (over 74%) in the same agro-ecology recognized the problem of water shortage particularly in drought years distantly followed by 44% in *woyna-dega*. Traveling longer distances to water points in *kola* indicates that households are spending much of their productive time fetching water and hence they are more sensitive to climatic risks. Moreover, these conditions forced the households to utilize water from unprotected sources with implications for commonness of water-borne human health problems, conflict among households over scarce water resources, and low water consumption for domestic and irrigation purposes, thereby aggravating vulnerability levels of the community to climate-related risks.

Kola agro-ecology, where the worst biophysical contexts exist, is more vulnerable to water poverty by almost all water indicators and climatic variables. *Kola* agro-ecology is characterized by flash floods associated with severe soil erosion as it receives higher rainfall for only July and August with less or no rainfall during the other months of the year. The fragile nature of the landscape in *kola* (being in the Abay Gorge) has resulted in increasing rate of run-off having very low underground



	Dega	Woynadega	Kola
Irrigation users	24	26.3	6.5
Area in hectare	6.24	8.5	4.6

Figure 12 | Number of irrigation users and irrigated farmland size by agro-ecology.

water potential through reducing rainwater infiltration and increasing evaporation from surface water.

All findings of this study call for appropriate adaptation interventions through integrated participatory watershed management in order to ensure sustainable environmental, economic and social development in the respective community. The study also concluded the need for spatially different adaptation measures as vulnerability is different among the three agro-ecological contexts.

ACKNOWLEDGEMENTS

The author wishes to thank the farmers for their cooperation, the enumerators who patiently carried out the household surveys, the experts at the district office of water resources development and development agents (DAs) at the specific study sites. The study was supported financially by the School of Graduate Studies of Addis Ababa University and University of Gondar. The paper has benefited substantially from anonymous reviewers.

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First received 5 December 2013; accepted in revised form 11 August 2015. Available online 16 September 2015